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# Embedded Fiber Optic Probes to Measure Detonation Velocities Using the Photonic Doppler Velocimeter

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# Embedded Fiber Optic Probes to Measure Detonation Velocities Using the PDV

WCI
WEAPONS
AND COMPLEX INTEGRATION

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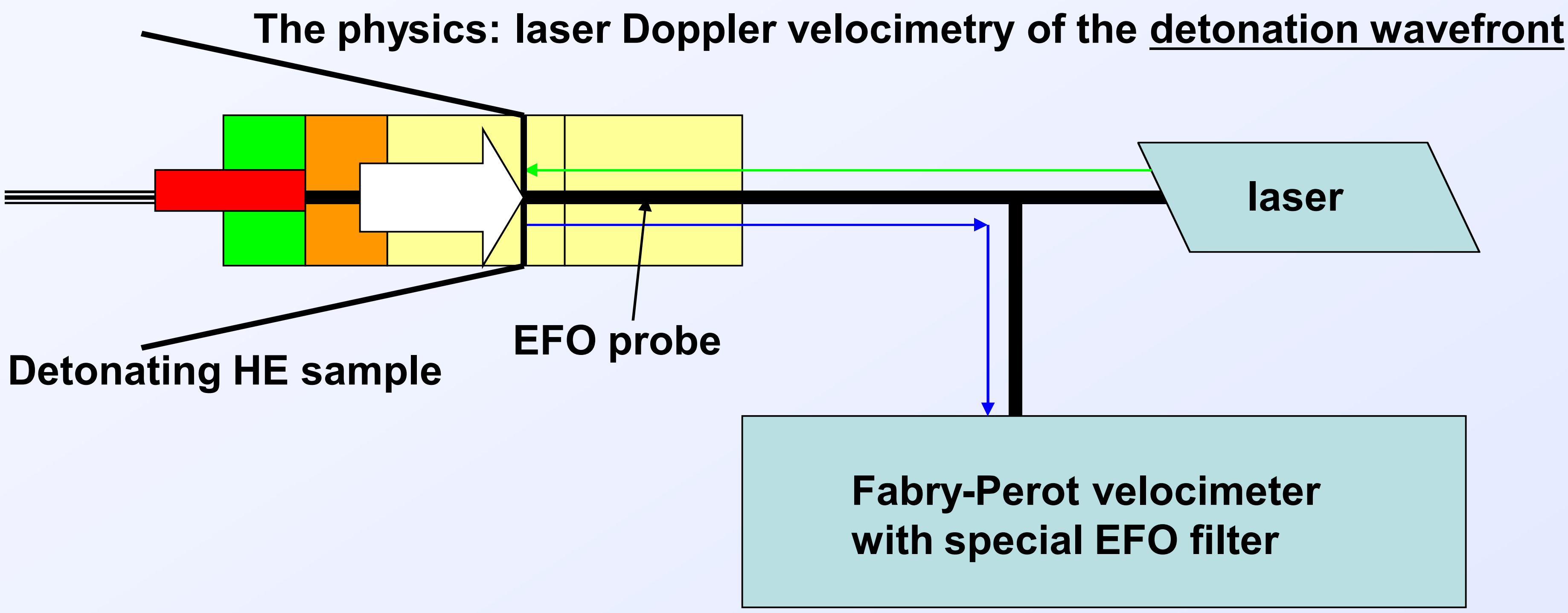
# Outline

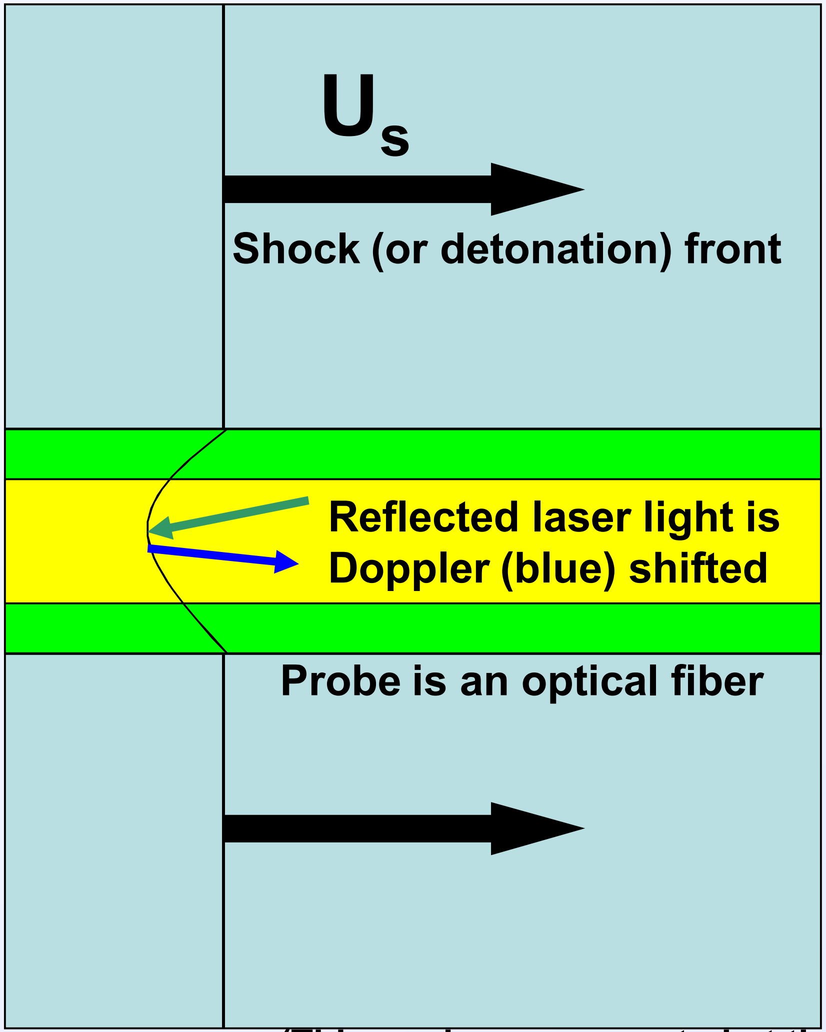
- Previous work with the Fabry-Perot Velocimeter
- Description of the Embedded Fiber Optic (EFO) probe
- Background of the PDV
- Experimental Setup for EFO Measurements
- Examples of the data
- Issues
- Conclusions

# Previous work with Fabry-Perot Velocimeter




(This work was presented at the 13th International Detonation Symposium, Norfolk, VA, July 23-28, 2006.)

# Previous work with Fabry-Perot Velocimeter




- Shock wave creates / maintains a refractive index discontinuity in probe core
- Index discontinuity:
  - Reflects laser light
  - Imparts a Doppler shift because it is moving
- In the case of steady flow:
  - The Doppler shift should be exactly the same as the steady shock or steady detonation speed

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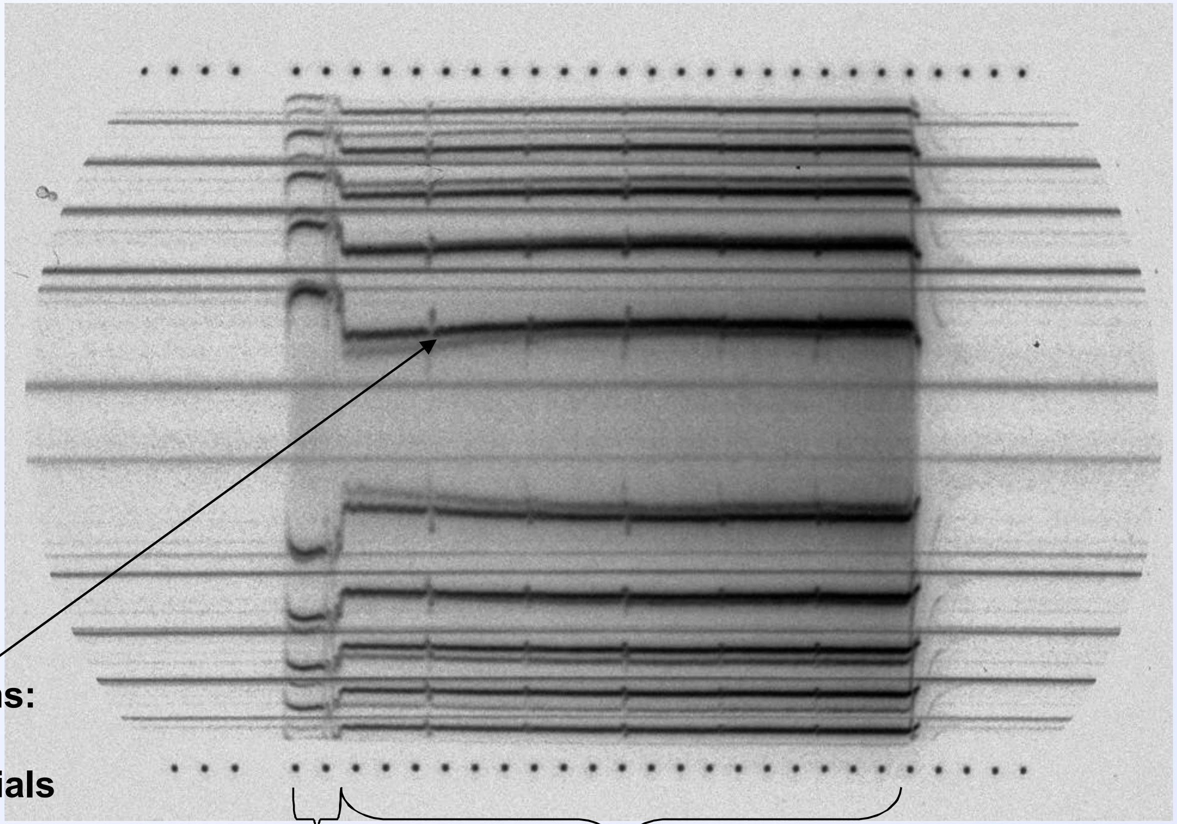
# Previous work with Fabry-Perot Velocimeter



Pellet junctions: Make good position fiducials

booster LX-17 or 9502 column

(This work was presented at the 13th International Detonation Symposium, Norfolk, VA, July 23-28, 2006.)

# EFO probe used with the Fabry-Perot Velocimeter has an aqueous solution of CsCl as its core

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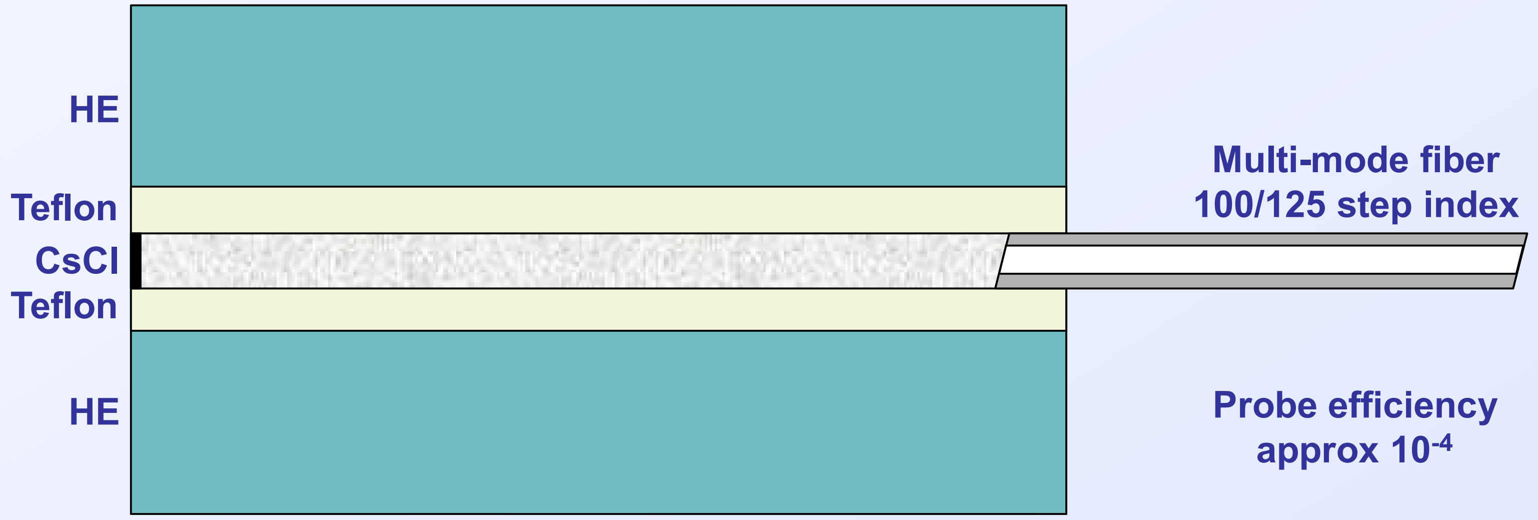
## EFO-FP probe

•Used with FP velocimeter at 532 nm

•PTFE (Teflon) cladding (1.6 mm OD, 127 μm ID)

•Aqueous CsCl solution core (127 μm OD)

•Will measure wave speeds > 1.9 km/s




Probe efficiency approx $10^{-4}$

Note the angle polish on the end of the fiber inside the EFO probe

# EFO probe used with PDV has a single mode fiber inserted into the Teflon tube

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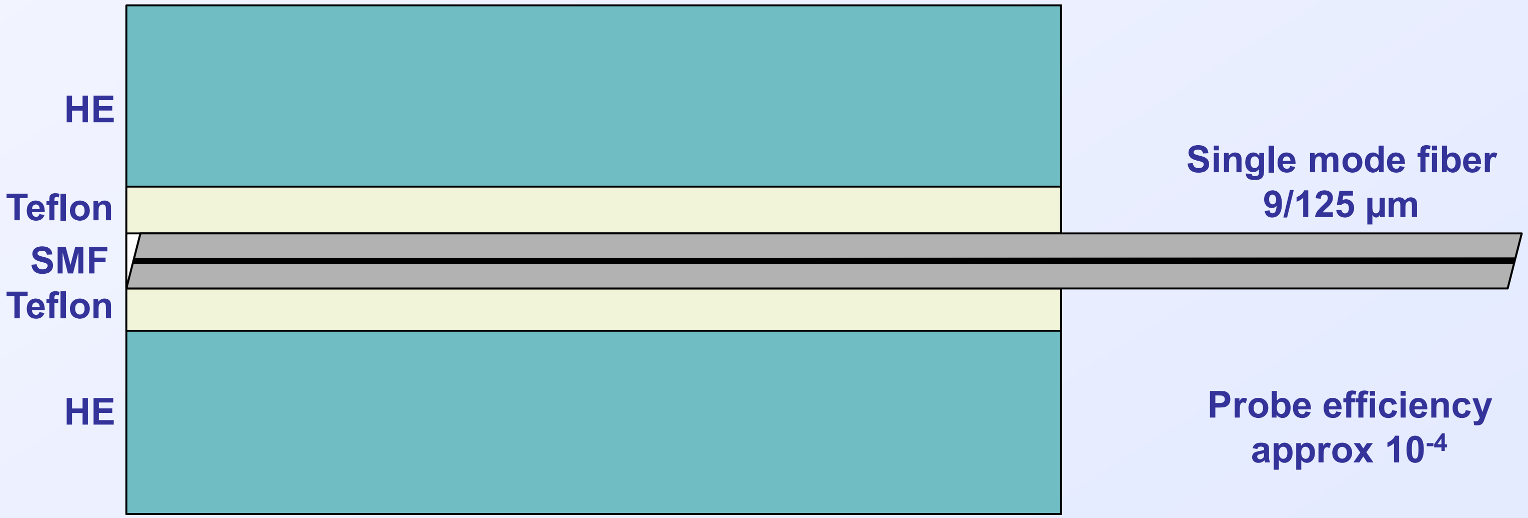
## EFO-PDV probe

- Used with PDV at 1550 nm
- PTFE (Teflon) cladding (1.6 mm OD, 127 µm ID)
- Single mode fiber (125 µm OD, 9 µm core)
- Will measure wave speeds > 5 km/s




Note the angle polish on the end of the fiber inside the EFO probe

# The index discontinuity of the shock front inside the core reflects the laser light back to the PDV

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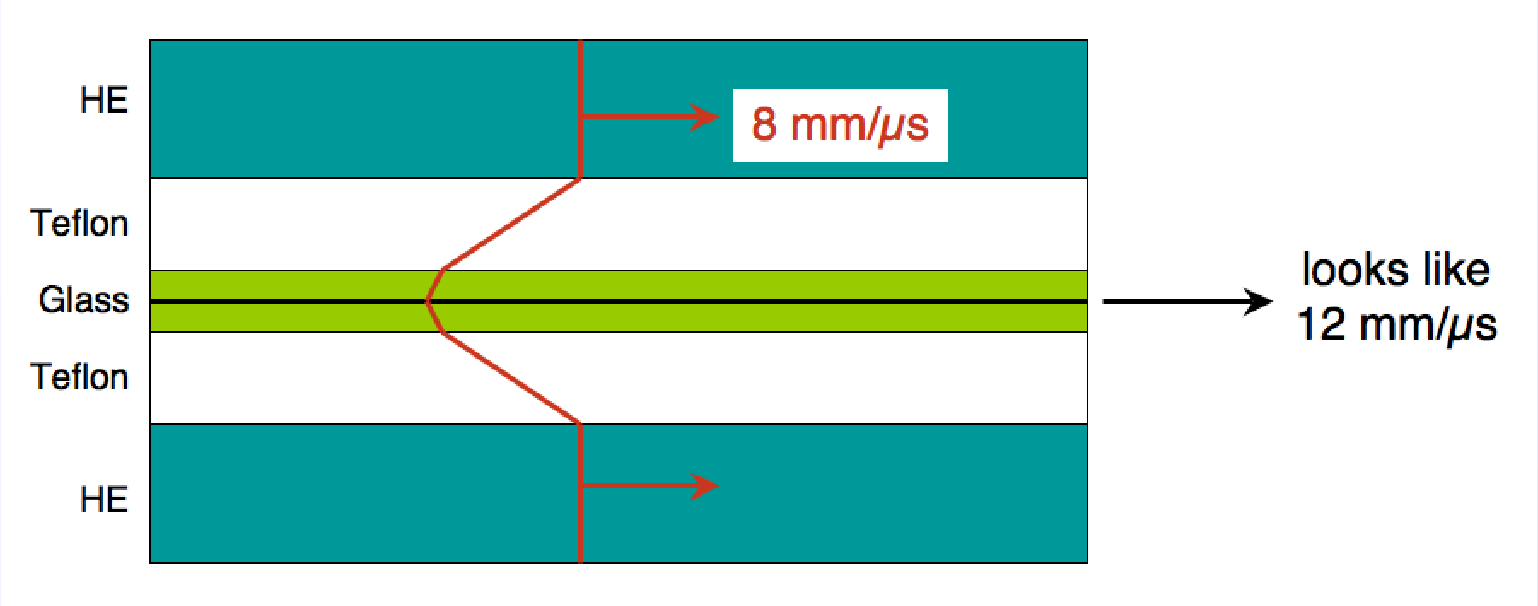
Approximately 1 x $10^{-4}$ efficiency

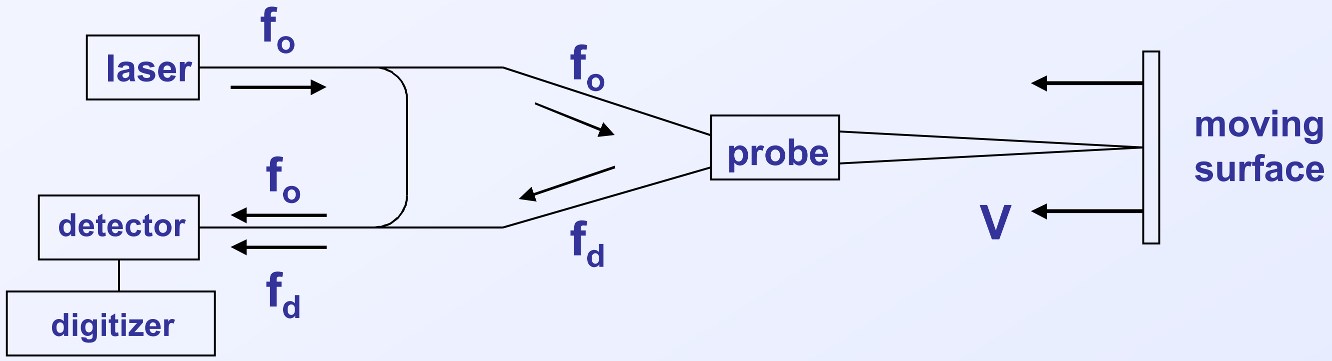



**The measured velocity is the time rate of change in the optical path length, which is the actual distance x the index of refraction.**

# The PDV operates by generating a beat frequency proportional to the velocity



**Develop velocimetry by mixing undoppler-shifted light with Doppler-shifted light and measuring the beat frequency**




Beat frequency = $f_b = f_d - f_o = 2(v/c)f_o$

Example: at 1550 nm and 1000 m/s:

$f_o$ = 193414.49 GHz
$f_d$ = 193415.78 GHz → $f_b$ = 1.29 GHz

# We use a 3-port optical circulator as the heart of the PDV

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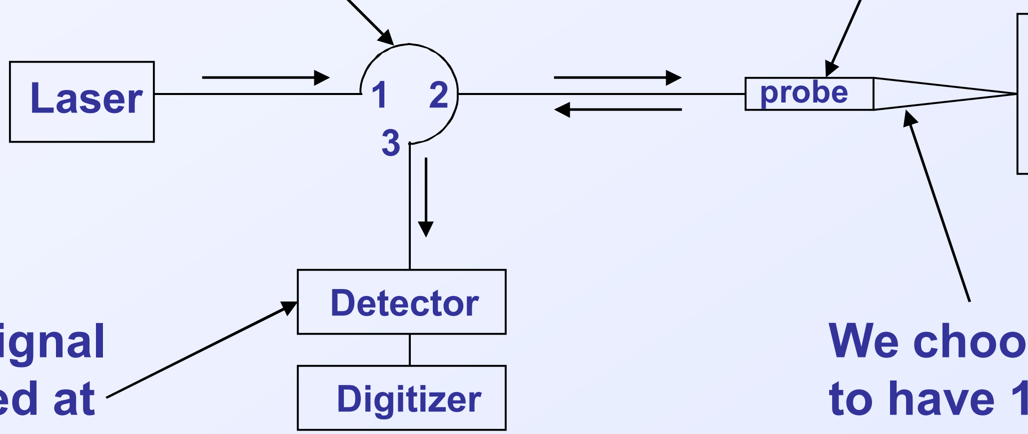
The circulator directs the light into the desired directions

We order the probes to have -40 dB return of the input light

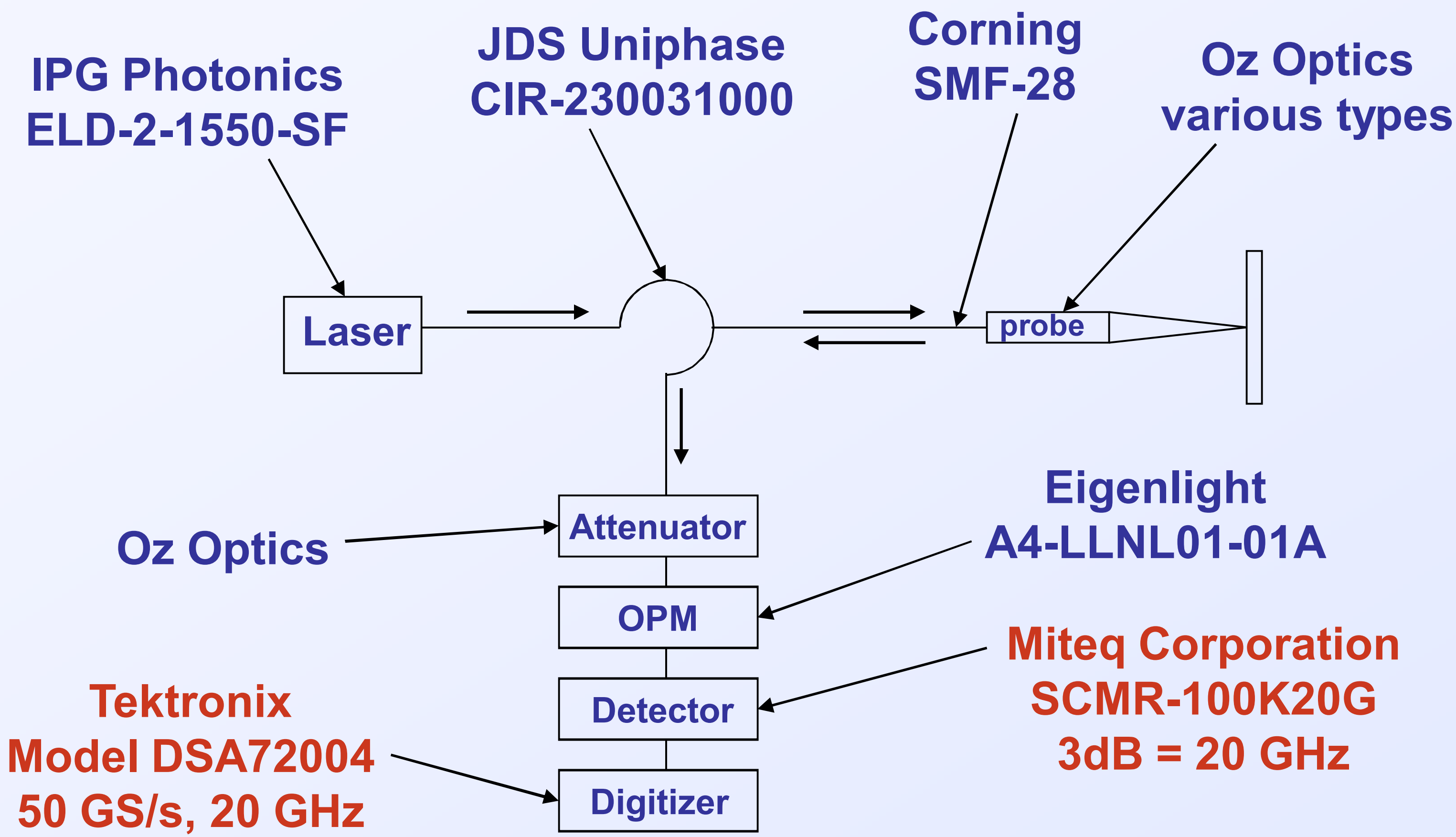
The fiber laser is easy to use




The beat signal is generated at the detector

We choose probes to have $1 \times 10^{-4}$ efficiency

# High bandwidth electronics allow the PDV to measure velocities over 12 km/s



# We package each 4-channel PDV system in a roll-around rack

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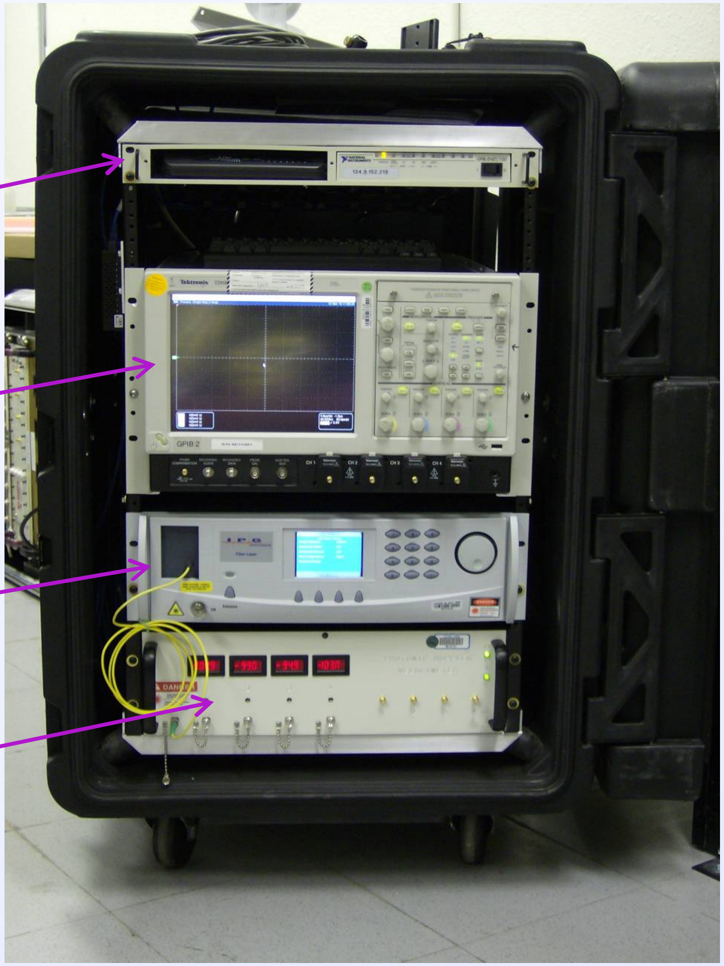
Ethernet

High bandwidth digitizer

2W fiber laser

Custom-built fiber/detector chassis

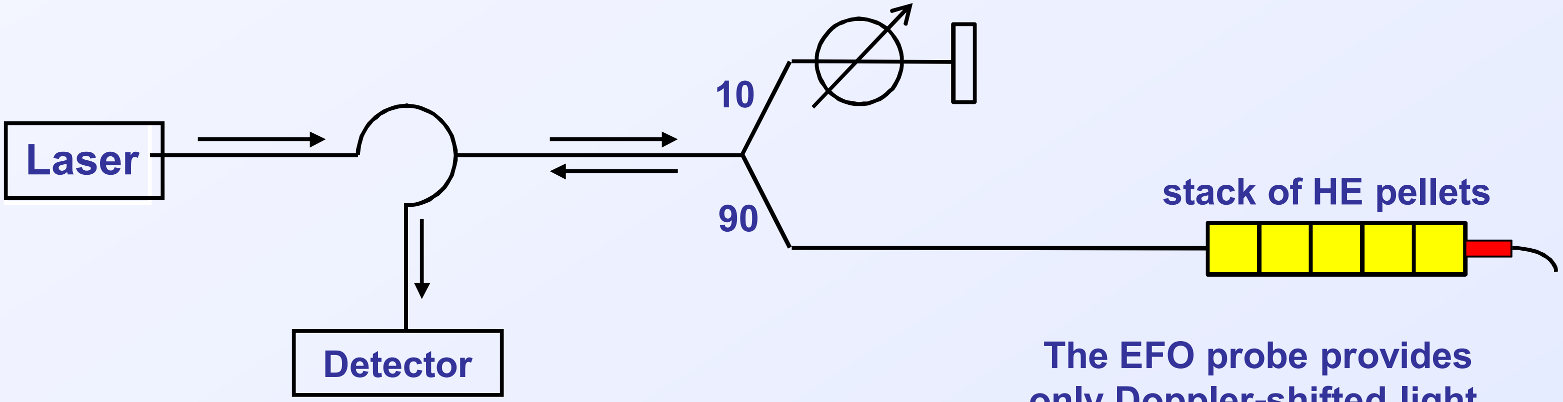


LANL has a modular format for the PDV chassis and can package 8 channels per rack

# We use a variable reflector to provide the reference signal

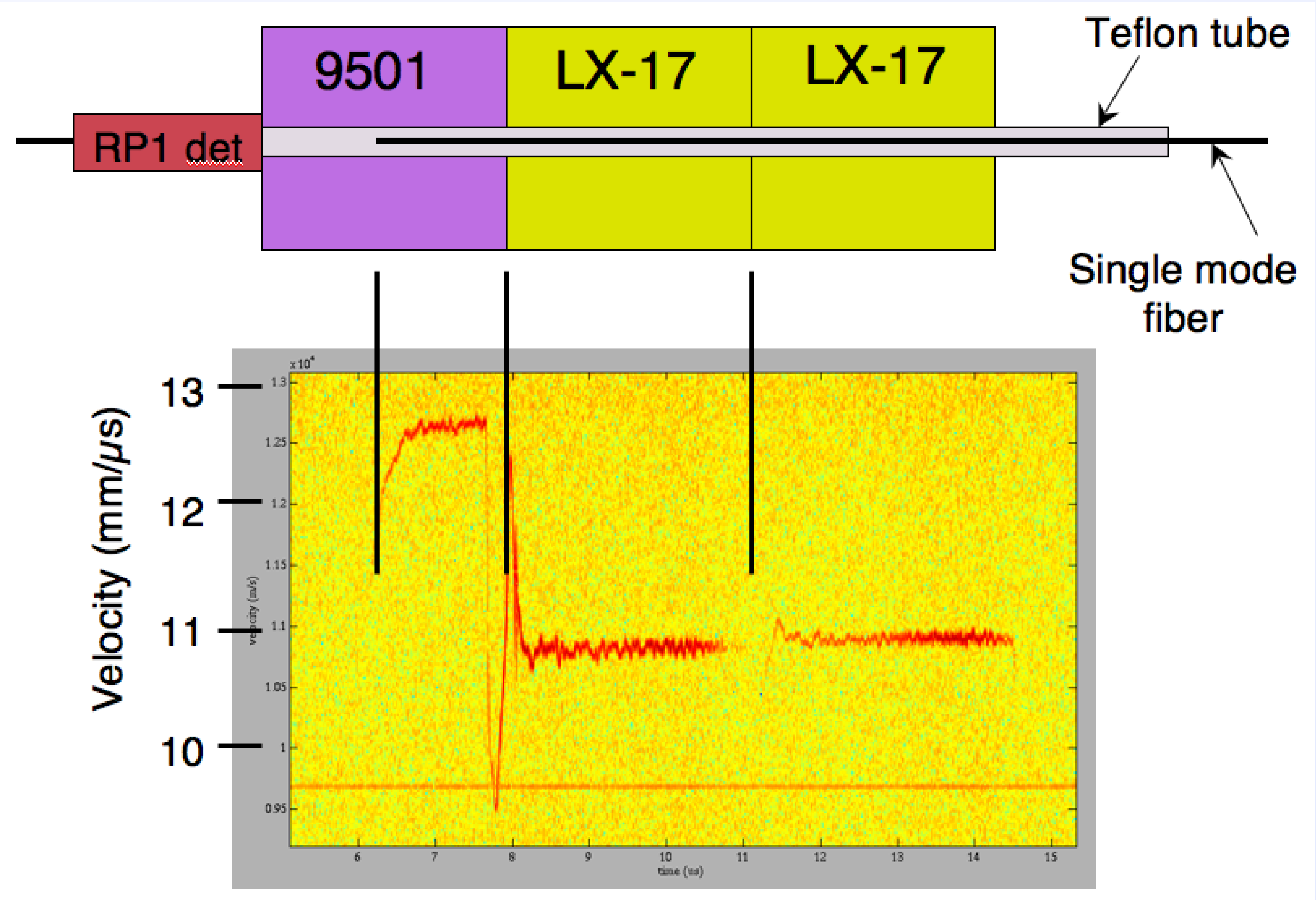


Variable reflector provides
our source of undoppler-shifted light

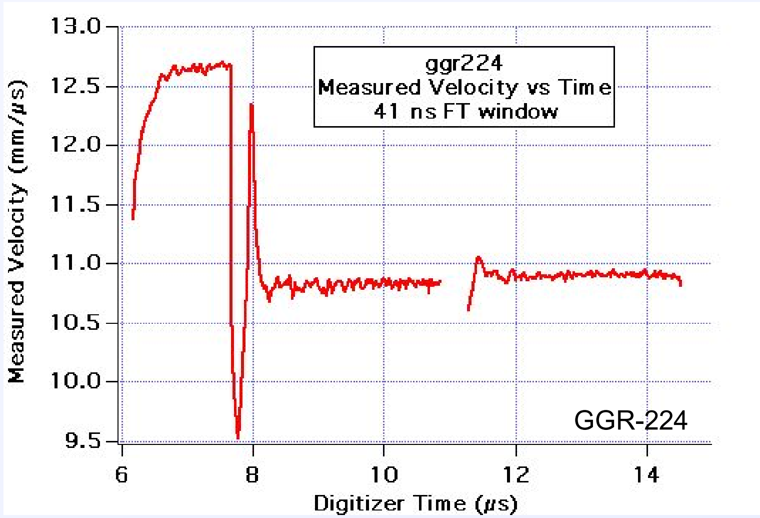


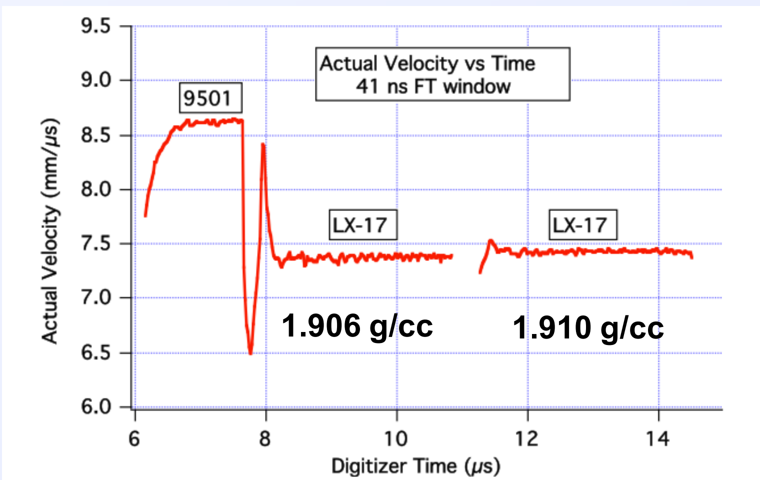

The EFO probe provides
only Doppler-shifted light,
so we need an external
reference source

# Over-driven LX-17 with on-axis detonator



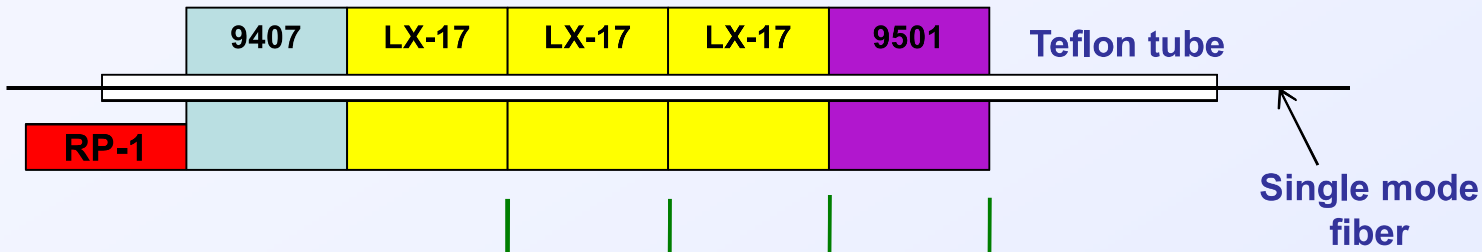
# Divide the measured velocity by the refractive index (1.4682) to obtain the actual velocity



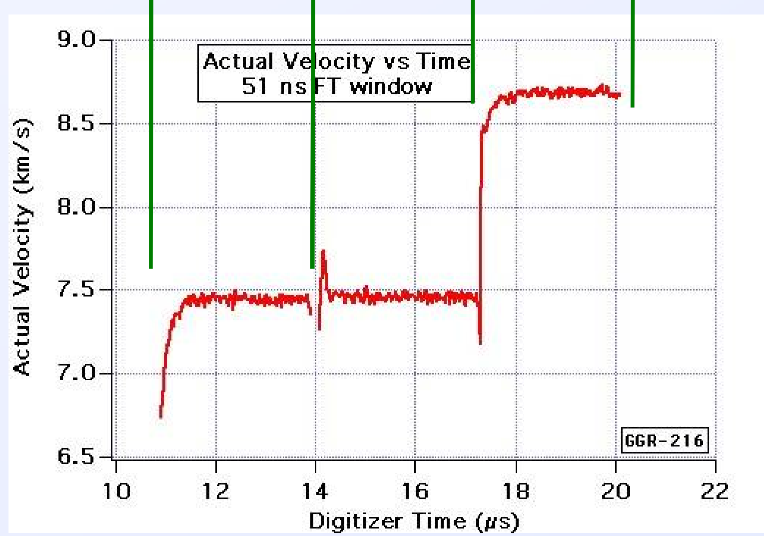




**Many thanks to Jim Crain of LANL for loaning us his TDS-6154 for this 1st set of shots.**

# Under-driven PBX-9501 with off-axis detonator




No data from 1st two pellets



# We believe the oscillations are caused by the granularity of the HE

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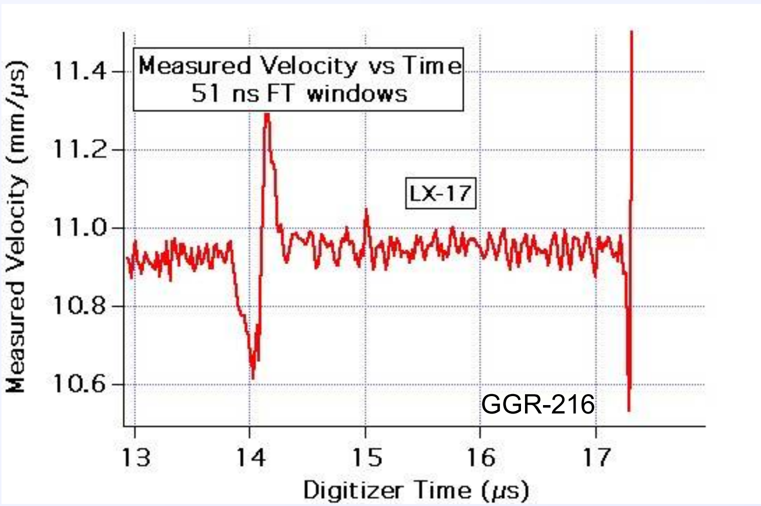
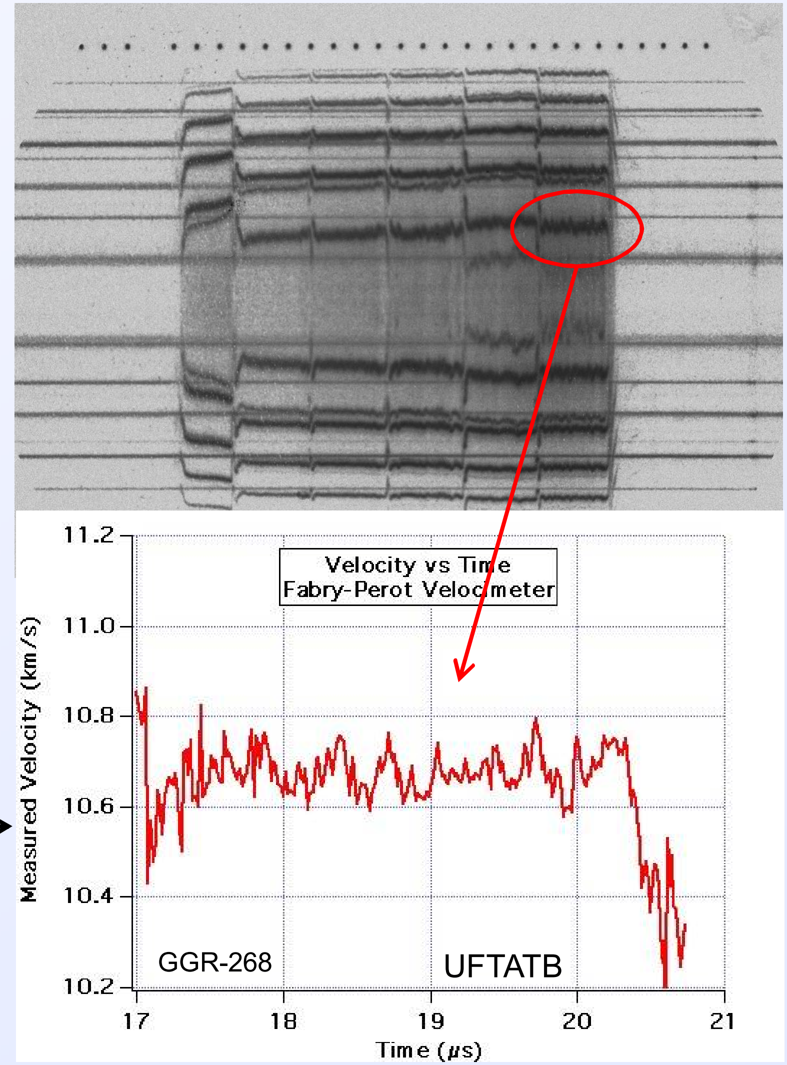
**This data is from the PDV EFO probe.**

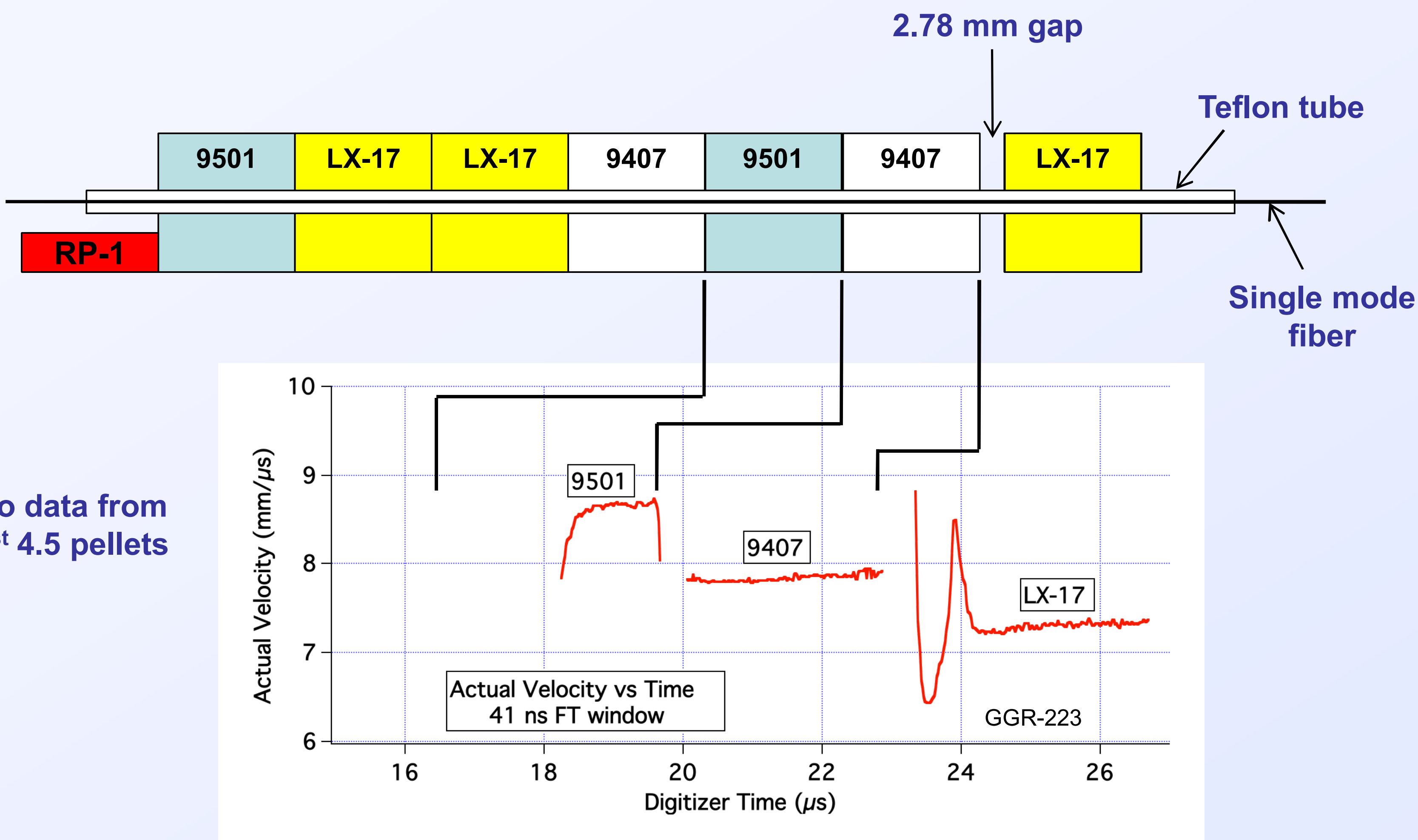



**We see the same type of oscillations with the Fabry-Perot EFO probe, also.**

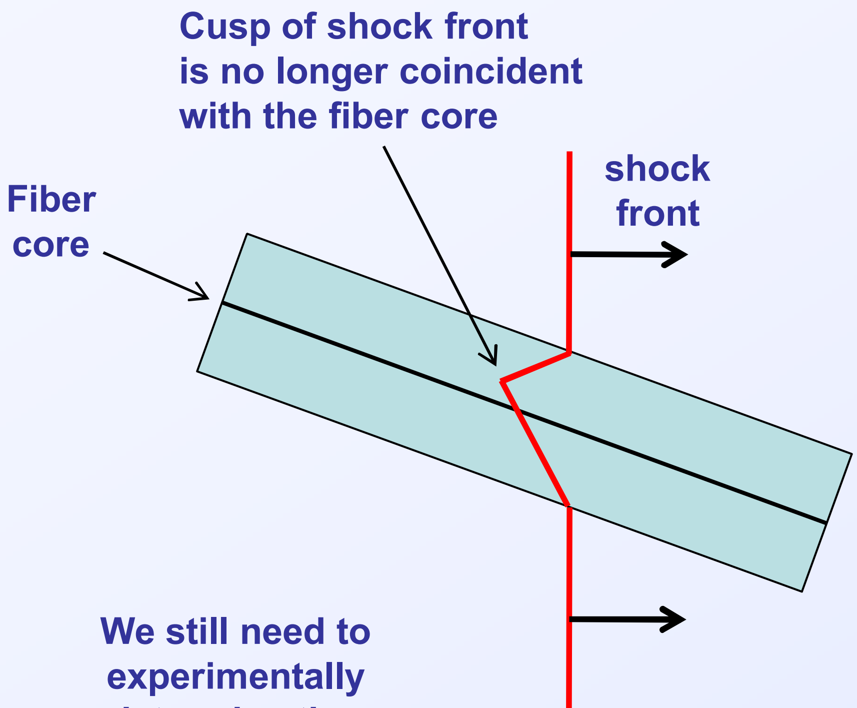
**Note: This level of detail is not possible using electrical pins for detonation velocity.**

# We observe that LX-17 detonates after a 2.78-mm gap

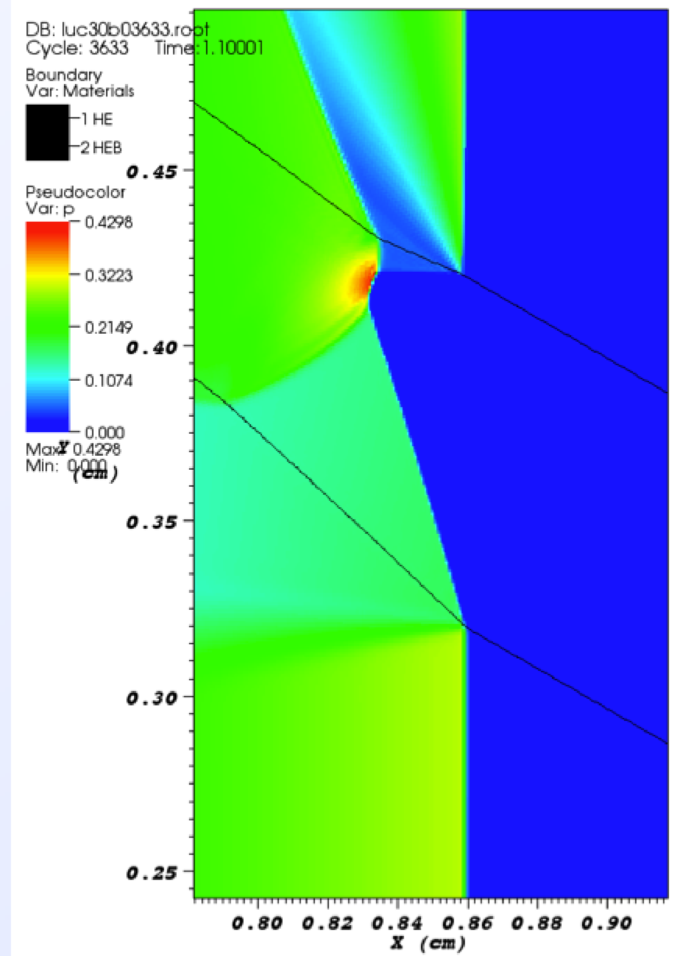



No data from
1st 4.5 pellets

# Issue #1:
# Detonation front must be nearly normal to the probe axis

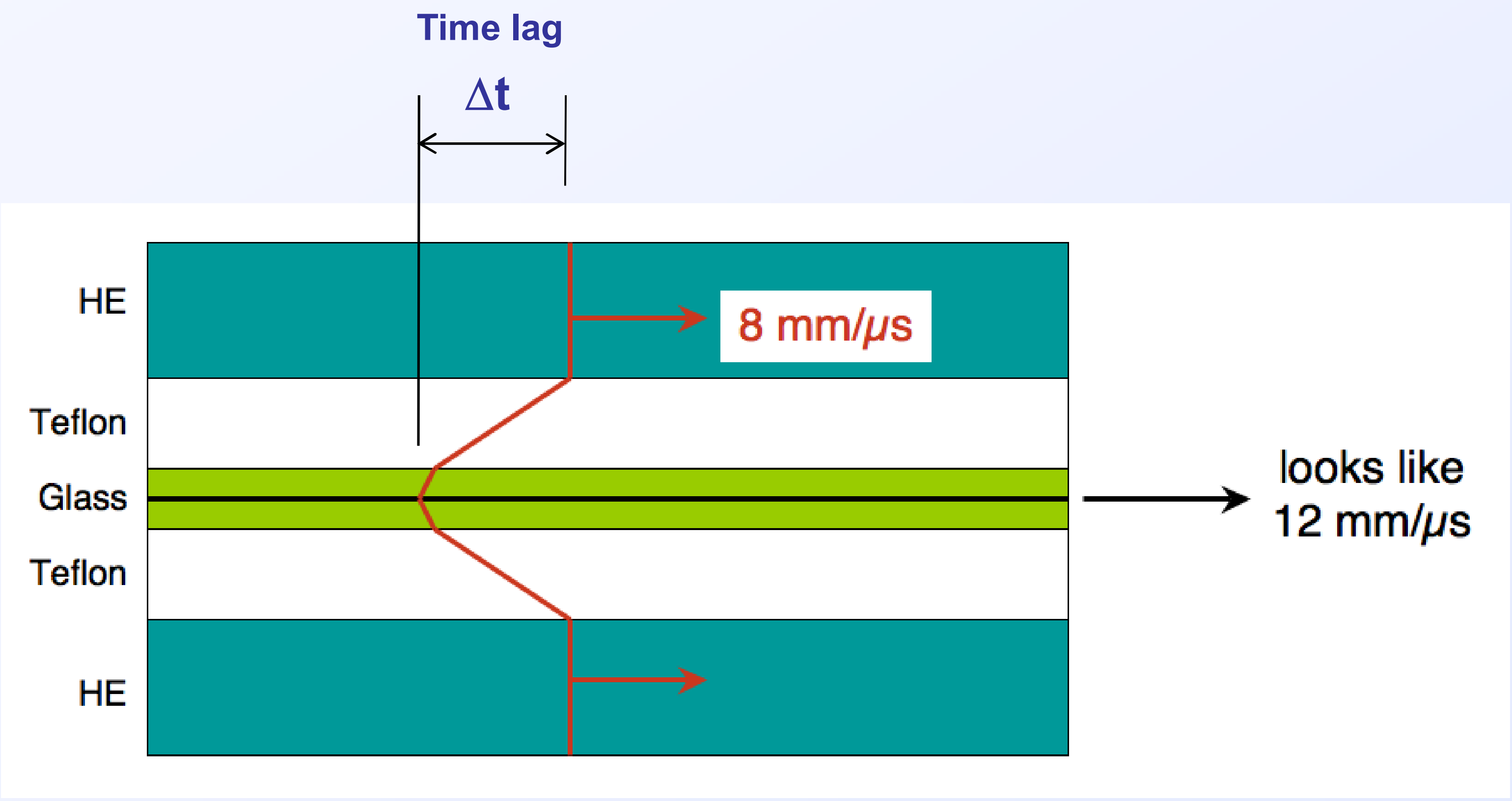



We still need to experimentally determine the maximum angle that returns data.




Computation by Ray Tolar, LLNL

# Issue #2:
# What are the time response and time lag of the PDV EFO?



# Conclusions

- We have developed an embedded fiber optic (EFO) probe for use with the Photonic Doppler Velocimeter.
- We have successfully obtained data with the PDV on several different HE stack-ups.
- The EFO-PDV probe has a Vmin of 5 km/s. We are investigating the use of plastic fibers with lower sound speeds.
- We still need to determine such parameters as time response, time lag, maximum angle with shock front.
- We wonder whether the normal index of refraction is the proper correction factor to use.